The Fossil Cliffs of
Joggins

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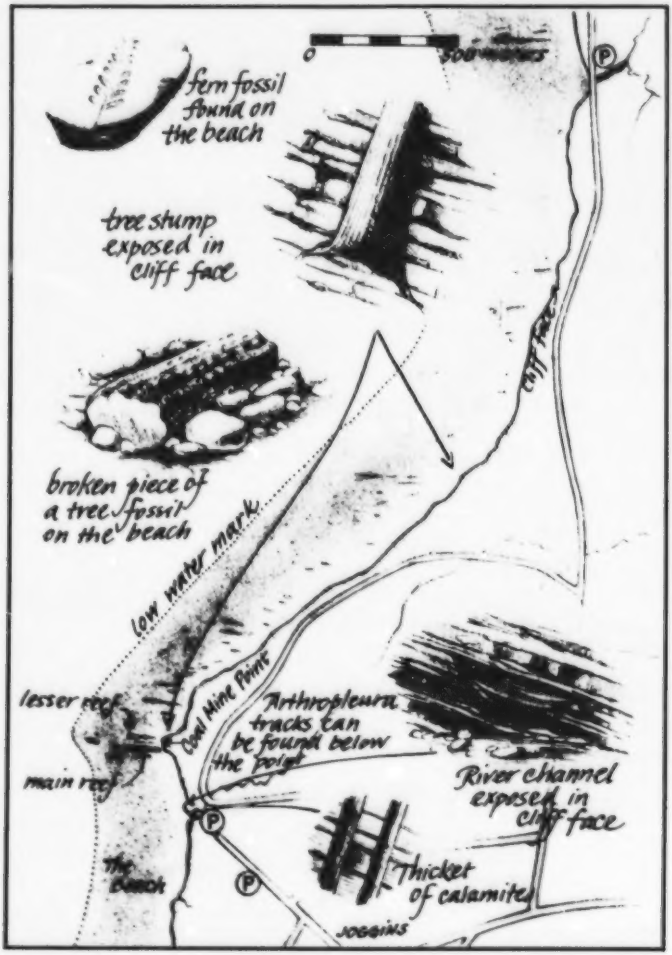

Joggins: what to look for

The Fossil Cliffs of Joggins

Laing Ferguson

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To my wife,
Joyce

Acknowledgements

Over the last twenty-five years, I have introduced thousands of people to the world-famous "fossil cliffs" at Joggins. I have learned a great deal from attempting to answer their questions and have decided to write this book to help other visitors understand the significance of the fossils they may see in the cliffs. I am grateful to those who asked the many thought-provoking questions that have led me to write the book. Financial assistance with the early stages of preparation of this book was provided by the Canadian Geological Foundation and the Marjorie Young Bell Faculty Fund of Mount Allison University.

The encouragement and assistance of members of the staff of the Nova Scotia Museum, especially John Hennigar-Shuh, Robert G. Grantham and Debra Burleson, is gratefully acknowledged. Dr. Erwin Zodrow and John Martell read and commented on an early draft, and Dr. Howard Donohoe, of the Nova Scotia Department of Mines and Energy, read a number of drafts of the manuscript and made invaluable comments. Helen Cook made very useful editorial suggestions. Finally, Etta Moffatt's illustrations added immeasurably to the clarity of my words and her design made the words and pictures work together most admirably.

ILLUSTRATIONS AND PHOTO CREDITS

Emeritus Professor Wilson N. Stewart of the University of Alberta has kindly allowed the use of illustrations from his book *Paleobotany and the Evolution of Plants* which are copyrighted by and reprinted with the permission of Cambridge University Press. These include the illustrations of the club mosses on page 20, the two illustrations of *Cordaites* on page 23 and the illustration of the *Cordaites* leaves on page 24.

I also acknowledge the generous co-operation of Robert L. Carroll of the Redpath Museum who let us use the figures on pages 14, 26 and 27. Dr. Peter McCabe of the U.S. Geological Survey, Denver, gave permission to use the block diagram showing sediment accumulation in a meandering river system which was the source of the re-drawn block diagram on page 33. Dr. Stephen Godfrey of McGill University allowed us to reproduce the reconstruction of *Dendrerpeton acadianum* which appears on page 30. Dr. Peter Wyllie kindly gave his permission for the use of the diagram on page 43, which originally appeared in his book, *The Way the Earth Works*, published by J. Wiley and Sons in 1976. The illustrations of *Lepidodendron* and *Sigillaria* on page 20 were adapted from illustrations by Steven M. Stanley which appeared in *Earth and Life Through Time*, copyright© 1986, W.H. Freeman and Company.

The illustrations of *Calamites* on page 24, *Pupa* and *Zonites* on page 28 and the two *Eosaurus acadianus* vertebrae on page 30 were originally published in Sir J. William Dawson's *Acadian Geology*, 4th edition, 1891, and the illustration on the title page is from Dawson's 1863 work, *Air-Breathers of the Coal Period*.

The majority of the diagrams have been adapted and redrawn by Etta Moffatt from original sketches by the author. Some have been adapted from other sources (as indicated), while yet others have been devised by Ms. Moffatt herself to help explain certain difficult points.

The photomicrograph on page 17 was taken by Dr. Peter Hacquebard of the Atlantic Geoscience Centre. The photographs of the leaf scars of *Lepidodendron* and *Sigillaria* on page 20 were supplied by the Field Museum of Natural History; they were originally used in this configuration by Steven M. Stanley in his *Earth and Life Through Time*, copyright© 1986, W.H. Freeman and Company. The photographs on pages 8, 37 and 48 were taken by Nova Scotia Museum staff. All the remaining photographs are the author's.

Warnings

ROCK FALLS

The cliffs at Joggins are very prone to collapse because they are battered by waves at each high tide. Rock falls are relatively frequent, so you should not get too close to any overhanging parts, especially in the spring when frost-heaved blocks might be ready to drop. If possible, wear a hard hat near the base of the cliffs.

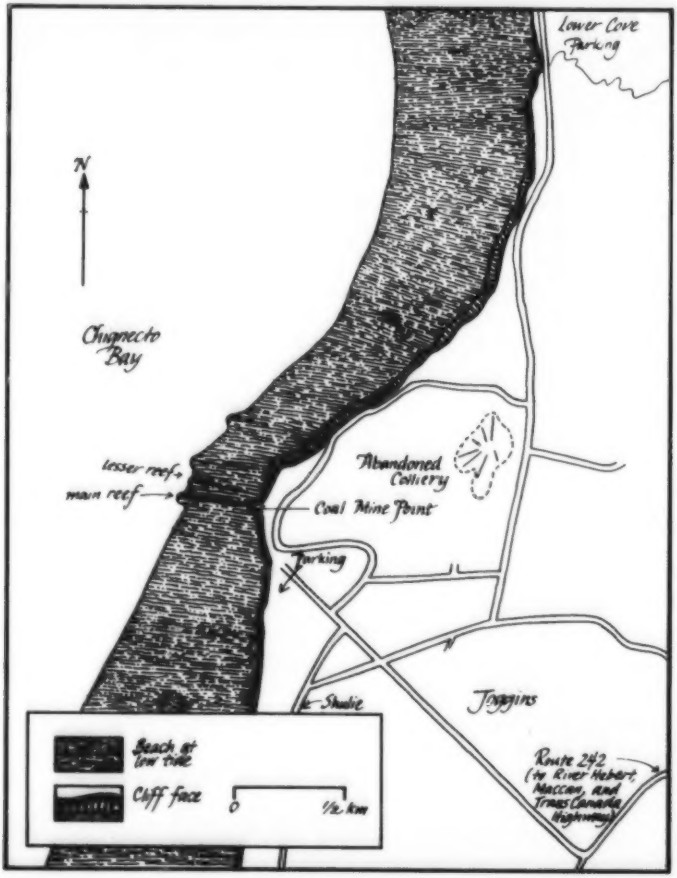
TIDES

The range is *very* high in the Bay of Fundy (up to 16 metres, or 53 feet, at the head of the Bay). Consult tide tables and plan to visit when the tide is going *out*, so you will have several hours on the shore without fear of the powerful incoming tides. Seaweed- and mud-covered rocks are *very slippery* when the tide has just gone off them, so the best time to visit the Joggins Section is during the three hours before and after low tide, preferably when low tide occurs after the sun is well up and the rocks have dried quickly.

Up-to-date *Canadian Tide and Current Tables Vol. I, Atlantic Coast and Bay of Fundy* are available from Fisheries and Environment Canada by writing: Printing and Publishing, Supply & Services Canada, Ottawa, Ontario K1A 0S9. They may also be available from the Maritime Resource Management Services office in Amherst, Nova Scotia, or from the Mount Allison University bookstore, Main Street, Sackville, New Brunswick. Announcements about the daily tides are also made frequently on Amherst radio station CKDH (900 on the dial).

FOSSIL COLLECTING

There are plenty of fossils on the beach and these *should* be collected or they will be slowly ground away by the incessant Fundy tides. However, you may not remove any fossils from the cliffs themselves without a Heritage Research Permit; the area is a "Protected Site." The fossils on the cliffs and in the "reefs" or ridges that are exposed across the beach at low tide may only have appeared very recently and should be left there to be examined by the paleontologists who visit the area regularly and have permits to collect. Even they must notify the Nova Scotia Museum of what they have collected.



Introduction

Joggins has long been popular with fossil buffs and novices alike for two very good reasons. First, it is always possible to find interesting fossils there, both exposed in the cliffs and on the beach. Second, Joggins always offers something new; winter frosts and the Fundy tides continually erode the cliffs so new fossils emerge each season.

Joggins is also of great interest to the scientific community and has made an important contribution to our understanding of how animal life evolved on earth millions of years ago.

The most obvious fossils at Joggins are the large fossilized tree stumps, some of which can be found every year emerging from the eroding cliffs. However, the fossils that gave Joggins its place in the development of evolutionary thought are the much smaller fossils of amphibians and some of the very first reptiles to have lived on earth. These had become fossilized inside the tree stumps.

Two pioneering paleontologists, Sir Charles Lyell (a friend and colleague of Sir Charles Darwin) and the great Canadian geologist Sir William Dawson, discovered these fossilized reptiles in 1851 and put Joggins on the world scientific map. Since then the site has yielded many valuable fossils and gained international recognition.

The International Geological Congress has met in Canada only twice, in 1913 and in 1972; on both occasions field trips were organized to Joggins. In recent years Joggins has also been visited by many groups of scientists attending other international scientific congresses in Canada, and is visited regularly by students from Canadian and American universities, museums and many local schools, as well as by tourists from all over the world.

This book was developed from a set of notes on the Joggins Section prepared for a field trip held in connection

with the International Geological Congress that took place in Montreal in 1972. Over the years these notes have been modified for non-geologists and students. More than two thousand xeroxed copies have now been distributed by the Nova Scotia Museum and the Joggins Tourist Bureau. This public interest in the fossils at Joggins has encouraged the publication of this guide to the fossil cliffs.

It is hoped that this book will stimulate your curiosity and encourage you to visit Joggins and search out its fossils. It will help you see what is there more clearly and understand it more fully.

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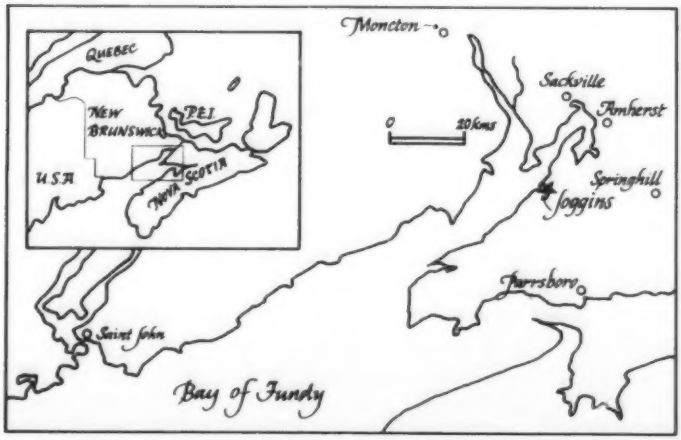
Joggins is a small village located on the northeastern shore of Chignecto Bay near the head of the Bay of Fundy and, as shown on the map below, is easily accessible by road after leaving the Trans-Canada Highway at Amherst or Springhill or from the south via Parrsboro on Highway #2.

Ample parking is available near the steps to the shore. Once on the beach, proceed northward (i.e., to the right) along the beach to examine the fossil cliffs. The map at the front of the book shows the best places to look.

For the enthusiast, a selection of publications for further reading on the fossils found at Joggins is given at the back of the book.



1

What You Will See at Joggins

Today, a visitor's first glimpse of the fossil cliffs at Joggins at low tide will be dominated by the sea cliffs and the expansive sweep of the tidal beach. Three hundred million years ago, however, when the plants and animals whose fossils are preserved in the cliffs and on the beach were alive, the landscape was completely different. At the time this area was covered with tropical vegetation and crossed by meandering rivers.

Arthropleura

This section gives an overview of what can be found at Joggins and sows the seeds for a fuller understanding of the characteristics of the rocks and the plant and animal fossils exposed in the cliffs. It also introduces the concept of geological time, and the notion that the now firm and static sedimentary rocks of the fossil cliffs at Joggins record the activities of very active river systems that flowed over the area 300 million years ago. These rivers meandered across jungle- or forest-covered plains inhabited by salamander-like amphibians and lizard-like reptiles, as well as by *Arthropleura*, a fascinating creature, that looked like a giant sowbug, about two metres long.

Approaching Joggins, you will notice various old waste heaps and other signs of the coal mining that used to be one of the economic mainstays of the area. The mines at

Springhill and Joggins itself closed down during the late 1950s, but until recently a coal mine operated at River Hebert. It should come as no surprise, then, to see seams of coal exposed on the beach and in the cliffs formed by erosion of the land at the edge of the Bay of Fundy.

Looking at the cliffs from a distance, you may not notice anything unusual. As you approach the cliffs, however, you will begin to see distinct layers. These layers of coal are the remains of junglelike forests that covered this area, and many others throughout the world, during a period of geological time some 360-285 million years ago appropriately known as the Carboniferous (or coal-bearing) Period. In North America, most of the coal beds were laid down during a period in Late Carboniferous times (320-285 million years ago). The beds exposed in the sea cliffs at Joggins were laid down from 310 to 300 million years ago. Just what that means in terms of the earth's vast history can best be placed in perspective by looking at the geological time scale on the next page.

THE CLIFFS

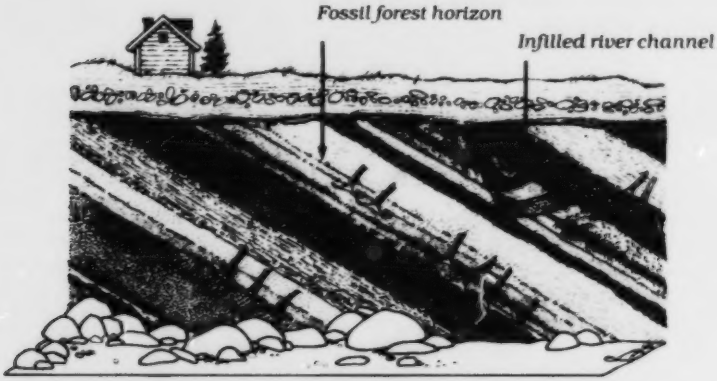
When you walk along the beach at Joggins and look up at the cliffs you will see that they consist of obvious layers, or beds, of sedimentary rock made from ancient sediments such as sand, silt and mud. These sediments were derived from the erosion, or wearing down, of other pre-existing rocks by the wind, rain and rivers during the Carboniferous Period.

The alternating beds of sandstone, siltstone and shale offer varying resistance to erosion by the Fundy tides. The more resistant layers are the grey and reddish-coloured sandstones, which are made up of relatively large sand grains of the hard mineral, quartz. The finer-grained rocks, such as siltstone and shale, are less resistant and easily scoured by the sand- and gravel-laden waves battering the base of the cliffs. These layers of sediment were originally laid down more or less horizontally but are now tilted to the south at an angle of about 20 degrees. It is important to know that the top of the layers faces to the south, so as you walk northwards up the beach towards Lower Cove you are actually passing by progressively older rocks, retracing the earth's history

ERA	Duration (millions of yrs.)	PERIOD	Duration (millions of yrs.)	(millions of yrs. ago)	EVOLUTION
Cenozoic	63	Quaternary	1		Early man
		Tertiary	62	1	Evolution of mammals
Mesozoic	157	Cretaceous	72	63	Extinction of dinosaurs
		Jurassic	46	135	First birds Dinosaurs flourish
		Triassic	39	181	First dinosaurs First mammals
Paleozoic	380	Permian	65	220	
		(Pennsylvanian) Carboniferous (Mississipian)	75	285 **300**	**Joggins** First reptiles
		Devonian	45	360	First land plants First amphibians
		Silurian	20	405	
		Ordovician	75	425	Invertebrates flourish First vertebrates
		Cambrian	100	500	Appearance of shelly fossils
				600	
Pre-Cambrian			3,900	3,500	Oldest fossils
				4,500	Origin of earth

perhaps hundreds or thousands of years with every step.

Near the top of the cliffs you will notice that the tilted layers of the Carboniferous rocks end abruptly and the uppermost 6 or 7 metres are made up of an irregular mass of clay and boulders. This thick layer of boulder clay is a much more recent feature and is actually a deposit left during the retreat of the ice sheet from the area a mere 13,000 years ago.

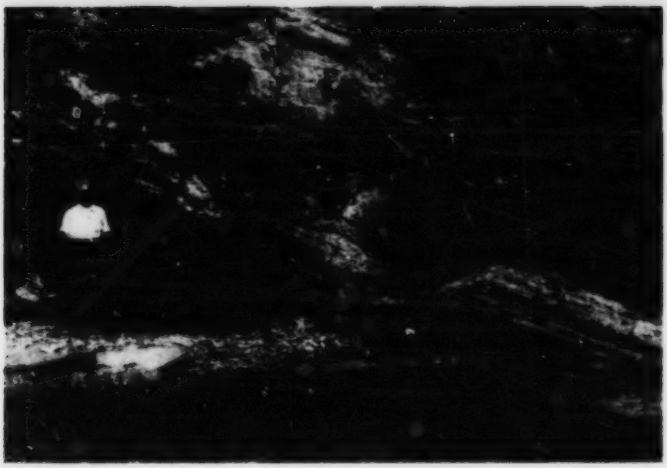


Closer examination of the tilted layers of sandstone reveals they are not as regular as they first seemed, but every so often have very obvious depressions in their undersides. These are ancient river channels which cut into the pile of accumulating flood plain deposits as the rivers changed course occasionally and were filled in during later floods.

The evidence in the pile of sediments has helped geologists understand how the sediment accumulated over millions of years in the Cumberland Basin. The Basin was originally formed by the sinking of a "block" of the earth's crust between two other upstanding and more resistant fault blocks—the Cobequid Mountains to the south and Caledonia Mountain to the west.

The evidence in the cliffs at Joggins suggests that, although the base of the Cumberland Basin sank several kilometers into the earth, the top was always slightly above sea level and was crossed by rivers. These rivers spread out the sediment they had eroded and transported from the uplands so the accumulation of the sediment kept pace with the sinking of the earth's crust.

Infilled river channel



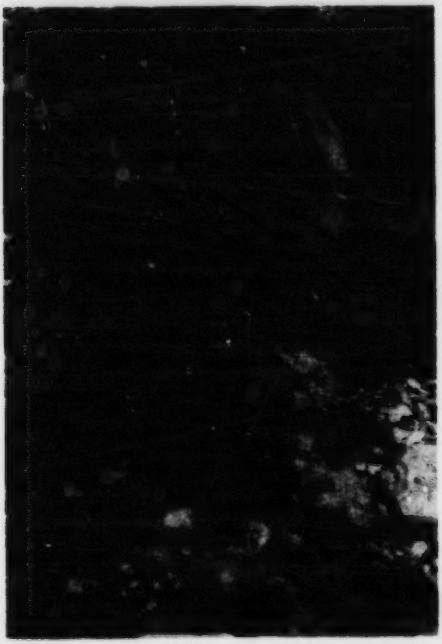
In addition to the sandstones, siltstones and shales, occasionally you will find a thin bed of black shiny coal and, under that, the remains of the soil in which the vegetation that was eventually transformed into coal grew. As well, fossil shells of lake-dwelling clams and other organisms are preserved in several thin limestone beds at certain levels of the Joggins cliffs, recording times when the rivers flooded their banks to form extensive shallow lakes and calcium carbonate was precipitated from the warm water onto the lake bottom.

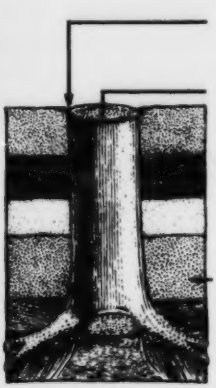
THE FOSSILS

Any evidence of ancient life may be called a fossil. Fossils are usually formed from the hard parts of organisms, since the soft parts decay more rapidly. For example, fossils of the *shells* of clams and sea urchins are more common than fossils including their soft parts. Fossils of soft-bodied animals such as jellyfish or worms are extremely rare worldwide, although impressions do occur. Similarly, the skeletons of reptiles or amphibians are much more likely to be preserved than the entire animal. However, it is not unusual to find the impressions left by certain of their soft parts—footprints, for example.

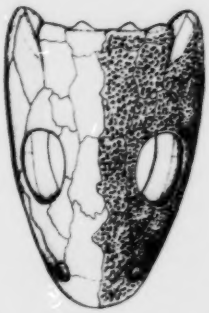
The most obvious fossils that you will see in the cliffs at Joggins are the tree stumps, like this large lycopod

stump, photographed in 1976 at the base of the cliff a few hundred metres north of Coal Mine Point. The lycopod was a large plant that flourished in Carboniferous times and was a giant ancestor of our present-day club mosses. The stumps range up to about one metre in diameter near the base and may reach several metres in height. Sometimes you can even trace extensive root systems for many metres from their bases. These fossils were formed by sediment accumulating on the river flood plains on which the trees had grown. The trees were killed when flood-swept sediments buried their bases. Later, their tops broke off and the soft pithy interiors of the stumps rotted away. Eventually, further sediments buried these hollow stumps and spilled in over their rims, filling them, as shown in the diagram below. So the fossil trees we find at Joggins today were moulded inside the hollow trunks of trees that actually stood on a river flood plain sometime between 310 and 300 million years ago. The more resistant bark of the trunk may be preserved as a centimetre-thick cylinder of coal around the outside of the fossilized trunk.





Remember, however, that the most obvious fossils are not the most important ones. From a scientific point of view, the most *important* fossils are those of the small vertebrate animals that fell into the hollowed-out trunks, most likely when the sediment surface was flush with their rims. In this state the hollow trees formed ideal traps, which were then rapidly filled by sediment. The animals that fell into the trunks and were preserved for posterity were amphibians and some of the very first reptiles that evolved on earth—the ancestors of both the dinosaurs of the Mesozoic Era and present-day crocodiles and other reptiles.



Amphibian skull (half-size)

It is quite common to find the remains of amphibians and *aquatic* reptiles in Carboniferous sedimentary deposits in other areas. However, Joggins is unusual in that the tree stumps provided the necessary trap and very rapid burial needed to preserve truly *terrestrial* (land-living) forms. It is this preferential preservation of these early terrestrial reptiles inside the upright fossil tree stumps that has made Joggins famous.

You can see how tree stumps containing the bones of reptiles and amphibians found at Joggins fulfilled the main conditions necessary for fossilization: the possession of hard parts such as bark and bones, and rapid burial in a protective medium, in this case the sediment dumped in and around the tree stumps by flooding rivers.

Remember that fossilization can occur in various ways. The trees at Joggins are essentially cylinders of coal filled with sediment, not petrified trees whose woody tissues have been replaced by mineral matter cell by cell, like the famous trees of the Petrified Forest in Arizona.

2

Plant Fossils Found at Joggins

When you visit Joggins you will almost certainly see at least a few examples of fossilized tree trunks. Some years more than 30 stumps of varying length and diameter have been observed around Coal Mine Point. Cliff erosion is so severe, however, that a tree is rarely exposed for more than four years before it is demolished by the waves.

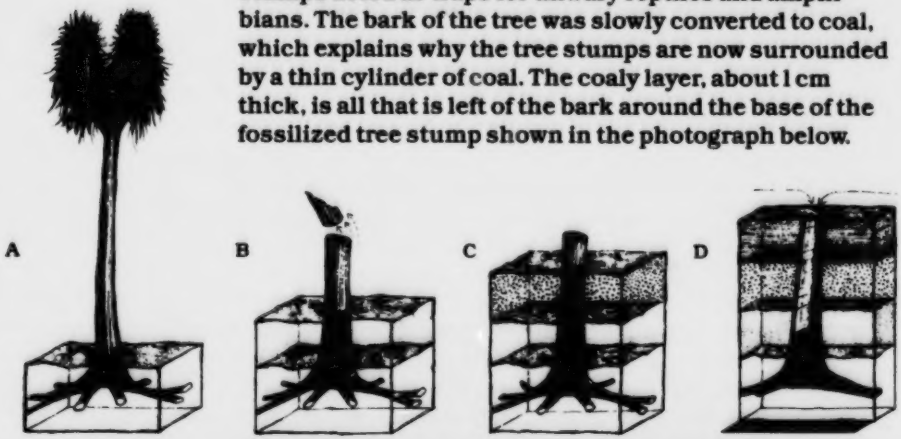
Let's take a closer look now at the various ways the stumps of trees have been preserved at Joggins. It is highly unlikely that you will see evidence of all these modes of preservation on a single trip. Don't despair. This book is based on observations made over more than a quarter of a century. What follows, however, should give you many clues about what to look for in your search for fossils at Joggins and help you to understand what you see.

HOW THE FOSSIL TREES WERE PRESERVED

The sequence of diagrams on the following page, shows how a lycopod tree at Joggins was gradually preserved. The bottom of each stump you see and any preserved roots are commonly surrounded by shale, and this is overlain by several feet of sandstone, which surrounds the lower part of the trunk. We know that shale is formed when mud becomes rock under pressure and that sandstone was originally sand.

So the sequence of sedimentary rocks we find around the base of the fossil trees at Joggins suggests that mud was slowly deposited in the flood plain, permitting trees to become established and grow to maturity (A). Then, when the river burst its banks after a heavy rainfall, it brought in coarser sediment from the river channel which surrounded the tree and killed it. Later, the top of

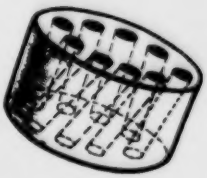
the tree was blown over by wind, leaving only a hollow stump (B). The inner tissues of the stump continued to rot as sediment accumulated around the trunk over the years (C). After the interior rotted and the upper part of the tree was removed, sediment accumulated until it reached the rim of the trunk, spilled into its interior and rapidly filled it (D). It was at this stage that the hollow stumps acted as traps for unwary reptiles and amphibians. The bark of the tree was slowly converted to coal, which explains why the tree stumps are now surrounded by a thin cylinder of coal. The coaly layer, about 1 cm thick, is all that is left of the bark around the base of the fossilized tree stump shown in the photograph below.

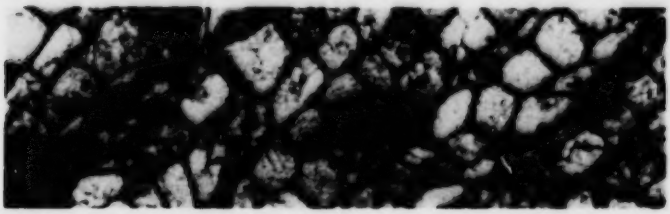


The water-conducting vascular tissue of the lycopod tree was primarily restricted to a zone just below the hard bark, while the centre of the trunk was occupied by soft pith that would rot rapidly, leaving a hollow cylinder

of bark. If the trunk had been filled in very early by water-laden sediment, the woody vascular tissues inside could have become petrified, a process in which the woody tissues are gradually replaced by mineral matter, such as calcium carbonate, so that the details of every cell of the wood are preserved.

However, only one such trunk has been found by the writer in more than a quarter of a century. In this case, eight or nine large vascular bundles about 5 or 6 cm in diameter spiralled up the inside of the trunk just in from the bark and the woody tissue was preserved in remarkable detail. The photograph below has been greatly enlarged to show the woody tissues of one of the petrified vascular bundles. The marginal sketch shows how these rope-like vascular bundles were positioned in the trunk.



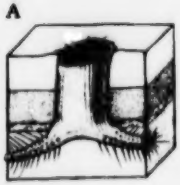


In most cases the pith and rope-like vascular bundles rotted and collapsed to the bottom of the hollowed-out trunk, so usually we find what Dawson referred to as a layer of "mineral charcoal" near the base of the material that infilled the trunks. Often there is no such layer of charcoal, however, suggesting that any plant debris that had been there completely rotted away before any other material had time to enter the trunk, bury it and preserve it as charcoal. These clues—the presence or absence and state of preservation of any organic tissues of the tree itself within its trunk—help us determine how rapidly the trunk was filled by sediment.

Other factors that obviously would control how long it would take for sediment to accumulate around a trunk and spill in over its rim are the actual height of the stump and the rate of accumulation of the sediment on the flood plain. The tree stumps you will find at Joggins were preserved in a variety of ways, as shown in the diagrams on the next two pages. Short stumps (A) would have been filled in at an earlier stage than taller stumps, which

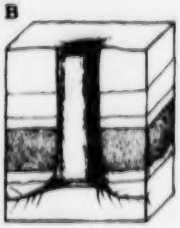
might have stood empty for a great many years before being filled in. Another clue for determining how trees were preserved is the state of preservation of their root systems. In relatively short tree stumps, from 1-1.5 metres high, the root system is commonly well preserved and was filled in by the first sediment that spilled in over the edge of the trunk. Presumably the hollowed-out roots were not overlain by sediment deep or thick enough to compact or cave in the roots themselves. In some cases the sediment-filled root systems spread out from the base of the trunks over a radius of 5 metres or more.

A



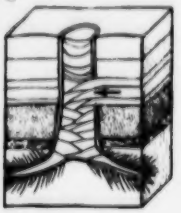
In longer tree stumps (B), the root systems usually caved in under the weight of overlying sediment long before the sediment surface had reached the level of the rim of the stump and started to infill it. This explains why long stumps rarely show well-preserved roots. In fact, at first sight they appear to have no roots at all. However, if you examine the bases of such stumps closely, you should see the position of the crushed roots and the rootlets that radiate out from them, as they do from the uncrushed roots.

B



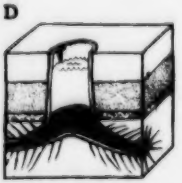
Some longer trunks may have had their base and root system filled at a relatively early stage by sediment entering the trunk through a hole in the side (C). The upper part of such breach-loaded trunks would have been infilled later in the normal way by material spilling in over the rim. The photograph on the next page will give you an idea of what to look for in the sea cliffs.

C



We know that some trunks stood empty for a long time before being filled with sediment because some fossil trees we find at Joggins have root systems that are filled with iron carbonate or siderite (D). This must have originated from mineral-rich groundwater that seeped into the hollow trunks and roots and then became so concentrated through evaporation that siderite was finally precipitated from it. Eventually, the upper parts of these trunks were infilled in the normal way by sediment spilling in over their rims.

D

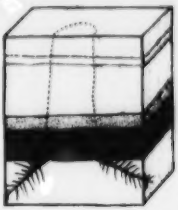


Sometimes sedimentation did not result in the preservation of the individual tree trunks. Nevertheless, we know the trees were once there because their root systems (complete with radiating rootlets) are visible just below the base of the coal seam to which the trees have

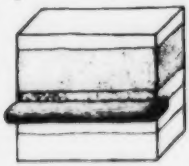
contributed their trunks (E). Cases like this suggest that the coal bed was formed by material that had grown at that spot, and not by material that had been transported into the area from some other site.

Horizontal tree trunks are rather rare in the Joggins Section for some unknown reason, but are found occasionally in the base of some of the larger river channels, such as Coal Mine Point itself (F), where they formed what looks like a rapidly accumulated log jam.

E



F



PLANTS OF THE CARBONIFEROUS PERIOD

Land plants obviously flourished during Carboniferous times because their remains form most of the extensive coal beds of that age all over the world. However, the plants that formed the Carboniferous coal swamp vegetation were, for the most part, not like our modern plants. None of the present-day flowering plants existed at that time, and the living relatives of most of the coal-forming plants are usually small and insignificant representatives of the types that grew in such lush abundance and grandeur in the Carboniferous forests. This section describes some of the trees and other plants that grew at Joggins more than 300 million years ago, and whose fossils are now so obvious and abundant there.

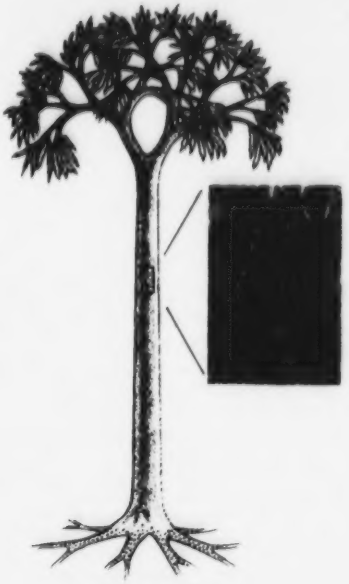
Club mosses

Lycopods

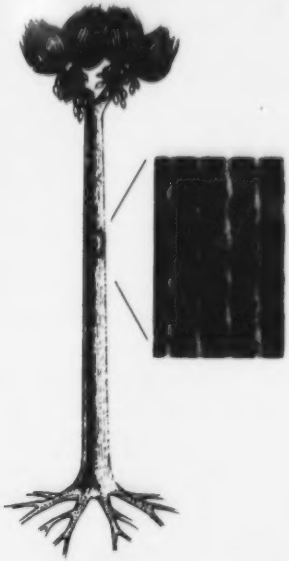
Most of the large trees whose trunks are preserved in the sedimentary rocks at Joggins were lycopods, or "scale trees." Our modern lycopods, club mosses, are small-scale relatives of some of their larger Carboniferous ancestors, and never grow to more than a few centimetres in height, like those illustrated here.

Their fossilized ancestors at Joggins are giants by comparison. In fact, some fossil stumps we find at Joggins are as much as a metre in diameter at the base. At first sight these fossils appear alike, especially near their bases. However, a closer look at the trunks often reveals different patterns of leaf scars on the bark where the scale-like leaves were once attached. These patterns of leaf scars are used to differentiate the various types of lycopod trees.

Two of the large fossil scale trees common at Joggins—*Lepidodendron* and *Sigillaria*—are pictured below. Both had trunks and branches that are now easily distinguished by the scale-like pattern of leaf scars found on



Lepidodendron

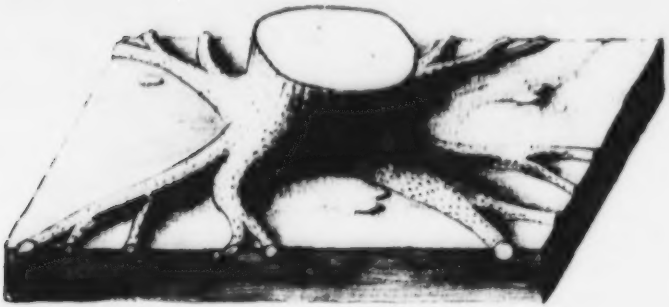


Sigillaria

their bark. *Lepidodendron*, the more common type, has a pattern of elongated diamond-shaped scars arranged in a spiral around its trunk. A variation was *Lepidophloios*, whose leaf scars are broader than they are long.

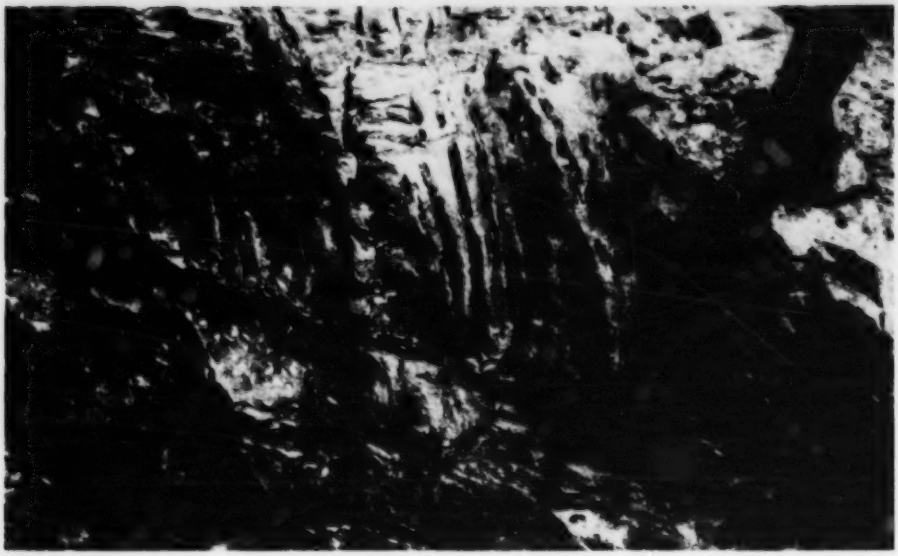
Sigillaria, like *Lepidodendron*, grew to about 30 metres in height. On its bark the leaf scars are arranged in vertical rows separated by ridges and are quite different from the other two types. Different types of *Sigillaria* can be distinguished at Joggins, but be cautious in trying to distinguish the different bark impressions in the sediment. Any one type may have different appearances, depending on how much it had rotted before having sediment pressed onto its surface. In other words, one type of fossil tree may appear differently depending on how much of its bark had weathered away prior to burial. It also makes a difference whether you are looking at the impression of the outside or the inside of the bark.

You may be able to distinguish the types of lycopod trees from the pattern of leaf scars on their bark, but not by their root systems, which are essentially the same. All fossil tree roots are referred to as *Stigmaria*, or stigmarian roots.



Segments of stigmarian roots are the most abundant and easily identified fossils to be found on the beach. Often you will see stigmarian roots spreading out from the base of the large trunks at Joggins; they were usually infilled with sediment through the trunk, and this sedi-

ment may contain fragments of rotten wood (now coal) from the interior of the trunk. The blade-like rootlets that radiated out from the main roots sometimes reached lengths of about 50 cm, and can be very obvious since they are preserved as black streaks of carbon about 1 cm wide. In some cases, the rotted rootlets appear to



have acted as channels for the migration of solutions rich in iron carbonate or siderite and are preserved as long rods of siderite that can be traced back to the stigmarian root.

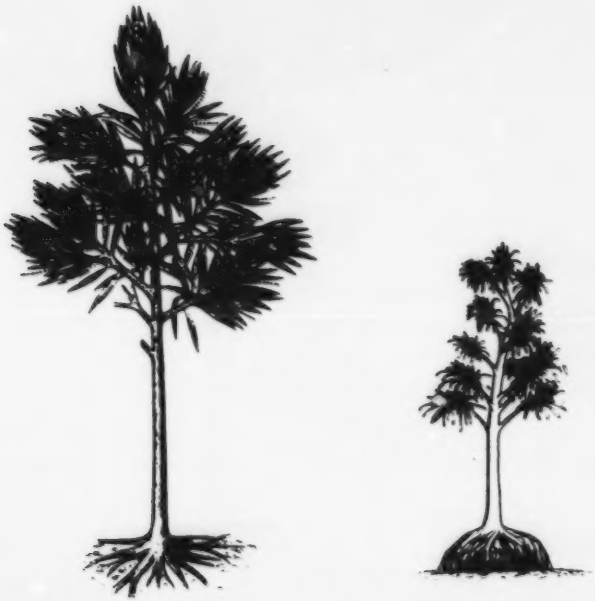
At Joggins you often can find roots still attached to tree trunks, which can be identified based on their bark. It is much more difficult, however, to establish the relationship of the fossilized leaves, fruit and even seeds and spores that are preserved, as these are not likely to be found still attached to the trunks. Land plants tended to break up before and during fossilization, creating problems for proper identification and classification. Sometimes this means that different parts of the same plant were classified separately and given different names. For example, the roots of a *Sigillaria* trunk are referred to as *Stigmaria*, the leaves *Sigillariphyllum*, and the fruit cone as *Sigillariostrobus*.

Cordaites and *Calamites*

Two other large tree-like plants common at Joggins are *Cordaites*, a primitive conifer, and *Calamites*, a tree-like ancestor of the present-day *Equisetum* or Horsetail, often found in ditches and marshy areas.

Cordaites belongs to a family of conifers (the Cordaitales) that appeared in Late Carboniferous times and flourished well into the Permian before becoming extinct, but is not a direct ancestor of our modern conifers, such as pines and firs.

There is some controversy over what *Cordaites* looked like. Many believe it to have been a large tree similar to the large lycopods, like *Lepidodendron*, about 30 metres high and with a trunk diameter of about one metre near its flared base. However, recently some paleobotanists have suggested that it was much smaller, in fact only about 5 metres high. They maintain that *Cordaites* had roots much like the present-day mangrove, and grew in swampy areas much as mangroves do. Both types are pictured below.



Cordaites *leaves*

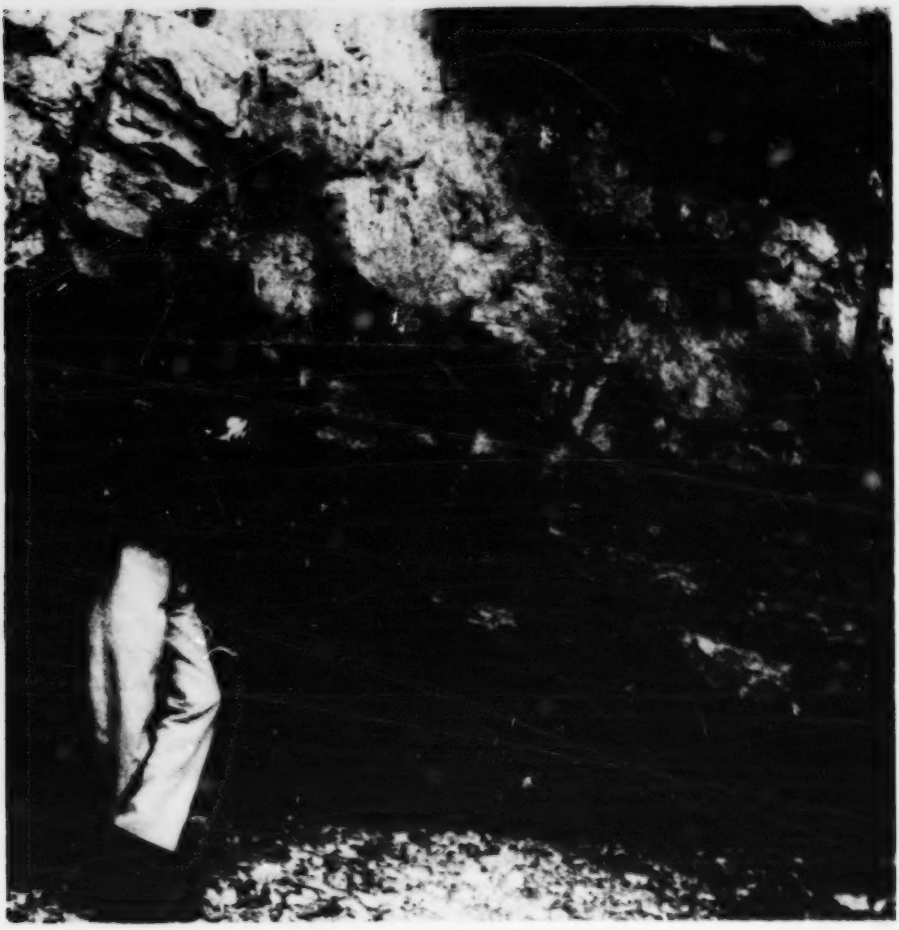
Calamites

The large strap-like leaves are quite often found in the rocks at Joggins. Some appear to have been up to about one metre long and about 15 cm across, and looked like the leaves of the common house plant *Amaryllis*. The distinctive pith casts referred to as *Artisia* are also considered to be from *Cordaites*, as are the large winged seeds known as *Samaropsis*, which are sometimes found in series or rows of up to nine seeds.

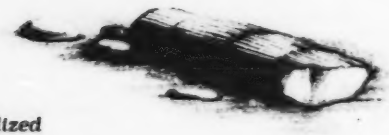
Calamites is one of the more common and easily identifiable fossils you will find. The plant resembled the present-day Horsetail and the related, but leafless, Scouring Rush, both of which are quite common in marshy areas but rarely grow more than about half a metre high. The *Calamites* that occur at Joggins can have a stem diameter of 10 cm or more, and are thought to have grown to a height of between 5 and 10 metres. As they grew, these plants formed a thick undergrowth among the large lycopods. Today they are usually preserved as pith casts (shown at right), which means the stems were filled in by sediment.

As soon as you arrive on the beach at Joggins, fossils in the first cliff you encounter will give you a dramatic picture of conditions in the forest primeval. A dense undergrowth of *Calamites* plants with stems up to about 10 cm in diameter has been preserved intact, along with occasionally exposed large- and medium-sized lycopod trunks; for example, one found in 1972 was about 90 cm in diameter and almost 3 metres high. The *Calamites* plants are spaced approximately 15-30 cm apart and, with their side branches intact, must have formed an almost impenetrable undergrowth around the larger trees, as shown in the photograph. The lower one and a half metres of these plants have been preserved and sometimes are even found with their needle-like leaves intact and penetrating the surrounding sediment. This could only have happened as a result of very rapid burial, such as one would expect when a river has burst its banks.

Fossils of ferns and other fern-like plants are also commonly found in the rocks at Joggins, and the fragments of the fern fronds look much like those of modern-day ferns.



A dense thicket of fossilized Calamites *in the cliff face just north of the stream at the start of the Section*



A piece of fossilized Calamites

3

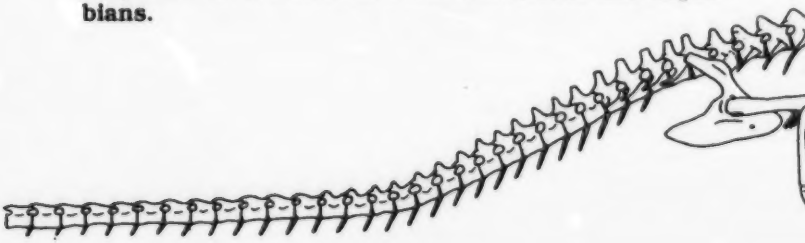
Animal Fossils Found at Joggins

While the most obvious fossils at Joggins are those of tree stumps, they are not the most important. Scientifically, the most important fossils at Joggins are those of the small vertebrate animals that fell into the hollowed-out tree trunks and were preserved for posterity. Vertebrates (animals with backbones) evolved from invertebrate animals during the Ordovician Period about 450 million years ago. The first vertebrates were the fishes. Amphibians evolved from fishes during the Late Devonian Period, invaded the land and flourished during the Devonian and Carboniferous periods. During the Late Carboniferous amphibians evolved into reptiles. Reptiles were able to colonize the land more efficiently and, with the development of dinosaurs, became the dominant life form during the Mesozoic Era. During the Mesozoic the reptiles gave rise to mammals, and to birds.

Dawson's reconstruction of Hylonomus lyelli

Some of the first reptiles to evolve on earth are to be found at Joggins, and this has made the site of world importance. ***Hylonomus lyelli***, reconstructed here, is one of the small reptiles that have been found inside tree stumps at Joggins. The skeleton below is close to life-size.

So when these little reptiles were scurrying along the floor of the Late Carboniferous forest at Joggins, the larger reptiles such as dinosaurs, as well as mammals, were still a long way off in the evolutionary sense. The only other vertebrates alive then were fishes and amphibians.



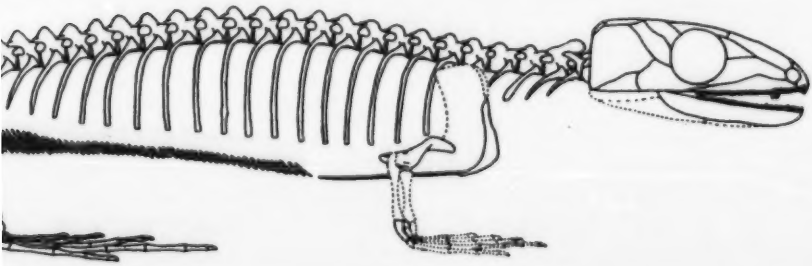
Many animals lived and swam in Carboniferous seas, but the rocks at Joggins were formed by the accumulation of sediments *on land* as well as the result of river action, or in freshwater lakes that developed from flooding rivers. The fossils that are found in these rocks are from land-dwelling or freshwater creatures. The great variety of animals that lived in the seas of the Carboniferous age are not fossilized in the sea cliffs at Joggins, so will not be dealt with in this book.

The remains of amphibians and *aquatic* reptiles are quite commonly found in Carboniferous sedimentary deposits in other areas of the world. Joggins is unusual because the tree stumps there provided the necessary traps and very rapid burial needed to preserve truly *terrestrial* forms of animal life. This is what has made Joggins so famous.

This section introduces the types of animals you might have encountered had you been able to trek through the Joggins jungle 300 million years ago and shows how they came to be preserved as fossils.

THE TREE STUMP ANIMALS

In *Acadian Geology*, Dawson vividly describes how the vertebrates that have made Joggins famous met their end inside their pit-like traps. In some cases the skeletons were entire; in others, the skeletons appear to have been torn apart by some later arrival in the trunk. Coprolites, fossilized droppings in the trunks, also indicate that at least some of the trapped animals survived for a time within the trunks and had something to eat—most likely



the carcasses of their predecessors. However, many of the animals that fell into the deeper hollowed-out stumps probably were fatally injured when they hit the bottom or drowned in standing water in the base of the stump. The others eventually starved to death or became the last food of the next captive. Up to seventeen skeletons have been found inside one trunk!

Dawson also recorded that a set of footprints from a small reptile was found impressed on the mud around the inside of the floor of a stump as the animal circled around in a vain attempt to climb up its sheer walls and escape.

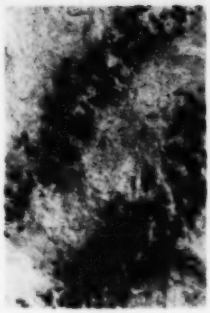
The insides of the tree trunks were inhabited by many creatures other than the reptiles and amphibians that fell into them. Dawson records at least two types of land snails (*Pupa* and *Zonites*), seen here greatly enlarged, that apparently lived in the hollow trees, as do many modern land snails. He also noted a small articulated worm-like creature, about 3 or 4 cm long, that he called *Xylobius* and referred to as a gally worm.

OTHER ANIMALS FOUND AT JOGGINS

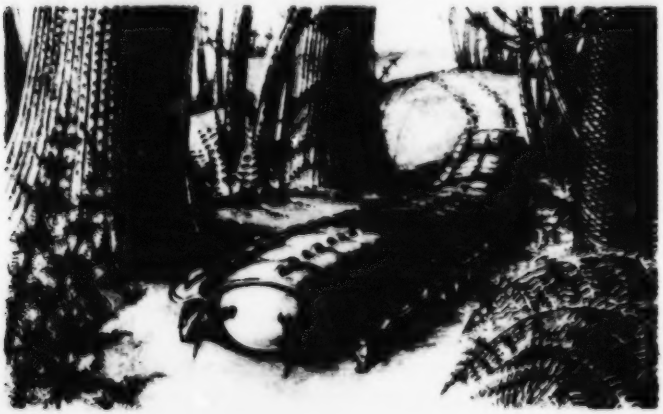
The fossilized animals found in the stumps at Joggins were truly land-dwelling vertebrates. As you can imagine, their more aquatic amphibian and reptile relatives and the fishes are not likely to have been preserved in the stumps themselves. However, their bones have been found in some of the lake deposits in the fossil cliffs. The stump fauna is also biased because it contains only the skeletons of those animals *small* enough to fall into the mouths of the hollow stumps and be trapped there. Larger reptiles and amphibians and very large centipede-like creatures, whose footprints are present on the sediment surface outside the trees, could go over or around the stumps without falling in.

Indeed, the most obvious evidence of former animal life at Joggins is not the remains of the animals themselves, but their footprints, tracks and trails. Some vertebrate animals too large to be trapped in the tree stumps left their footprints in the sediment surrounding the trunks, as did the smaller reptiles. The tracks you are most likely to see are those of a very large animal that

looked like an oversized woodlouse or sowbug, up to 2 metres long and 30 cm wide. These large millipede-like arthropods, known as *Arthropleura*, were never trapped in the hollow stumps because either they never lost their balance and fell into them or were able to scuttle their way right over the gaping hole. The animals themselves are never found intact since such invertebrates are very prone to falling apart after they die. Several fragments of *Arthropleura* have been identified from the sediments at Joggins, but the tracks, like these pictured here, are by far the most obvious evidence of their existence. They have been found at several levels from the beginning of the Section at the Joggins parking lot to Lower Cove at the north end. There are usually one or two sets of tracks exposed in the rock falls at Coal Mine Point itself. Trackways of small animals that look like present-day horseshoe crabs, 1 or 2 cm wide, are also found at Joggins.



The inside of a tree stump provided ideal conditions for the fossilization of any terrestrial animals that fell into it when the sediment surface had reached the rim of the trunk, since rapid burial by sediment was more or less assured. No such rapid burial in a protective medium was provided for reptiles or amphibians that died *outside* the tree stumps on the open floor of the forest. Such creatures were prone to the ravages of scavengers and to complete decay and, apart from footprints, their remains are almost totally missing from the surfaces between the trees. The only real exception to this would be areas where the remains could have been trapped in the muds

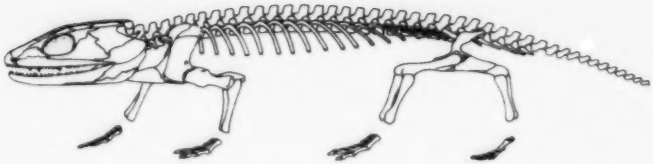


An Arthropleura makes its way across the floor of a Coal Age forest

of either abandoned river channels or the more extensive lakes formed by ponded-up river flood waters—the so-called aquatic beds.

In July 1987 a team of paleontologists from McGill University discovered the complete skull and entire skeleton of an amphibian in sediment not contained in a tree stump. Before this find only a few isolated, disjointed remains of vertebrates had been recorded from the aquatic beds. The two very large vertebrae (5 cm wide) shown here were thought to have belonged to a large aquatic reptile, *Eosaurus acadianus*, which Dawson believed was about 10 metres long. Other fossils found in the aquatic beds belonged to a variety of fishes.

In addition to the isolated remains of vertebrates, the aquatic beds abound in the shells of freshwater clams of various types, along with the remains of many different kinds of arthropods. These include the shells of "seed shrimps" or ostracods, minute creatures like water fleas that secrete a shell in two parts similar to that of a clam.



Reconstruction of the Dendrerpeton acadianum *discovered at Joggins in 1987*

4

Reading the Rocks

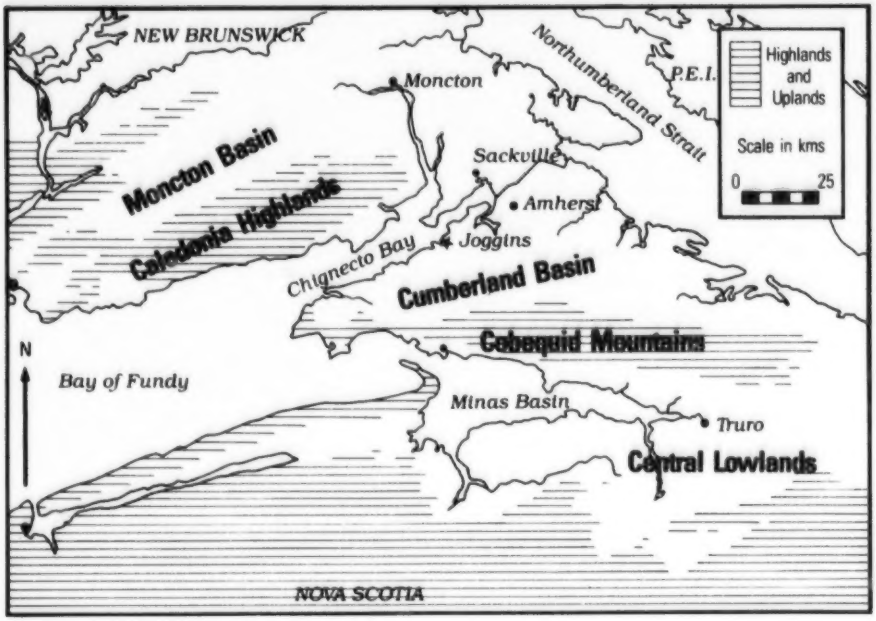
If you visited Joggins and paid attention only to the fossil trees and the occasional animal tracks that you found there, you would still be missing a very important and fascinating aspect of the story that the fossil cliffs have to tell. Although it stretches the meaning of the term *fossil*, the largest "fossils" at Joggins are the cliffs themselves. They are the fossilized remains of a succession of river channels and flood plains that occupied this area over a period of 10 million years up to 300 million years ago.

The story of these rivers and of the sand and mud they carried and deposited on their flood plains is written in the cliffs at Joggins. You can learn to read this story. All you need is an introduction to the kinds of sediments deposited by the rivers and to a set of telltale clues that geologists call sedimentary structures. These clues allow geologists to say with confidence that the rocks at Joggins are the result of river sedimentation rather than marine, desert or glacial conditions.

The Cumberland Basin is the name given by geologists to the area now occupied mainly by Cumberland County, Nova Scotia, and bounded to the south by the Cobequid Mountains and to the west by the Bay of Fundy and the Caledonia Mountain area of Fundy National Park. To the north and northeast the Basin extends into the Northumberland Strait.

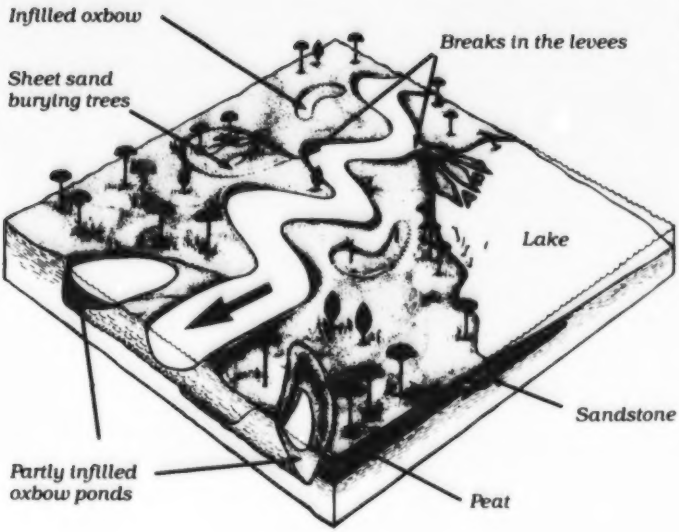
In Late Carboniferous times the entire Cumberland Basin was sinking rapidly as the underlying crust was depressed. (We'll look at why this was happening in the next chapter.) As the land subsided, rivers flowed into and across the Cumberland Basin from the high land to the south and west. These rivers carried sediment eroded from the mountains and, every time they flooded, the sediment was spread across the area to form a vast flood plain. The accumulation of sediments actually more or less kept pace with the sinking of the crust, so that although many thousands of metres of sediment ac-

cumulated over the 10 million years, the surface of the flood plain was always approximately at the same elevation above sea level. The cliffs at Joggins now give us an opportunity to examine some of the rock layers that accumulated in the Cumberland Basin and that have since been raised to the surface again. This section deals with the characteristics of the type of river sediments preserved so well at Joggins and will help you understand both the sedimentary layers exposed in the cliffs and the nature of the fossils they contain.



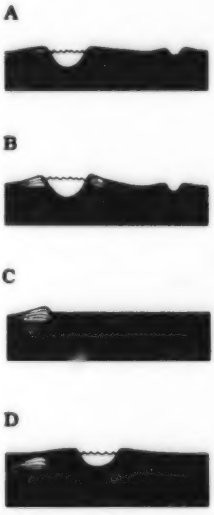
RIVER SEDIMENTATION

Imagine a meandering river such as the one shown in the diagram on the next page. Then try to relate it to the cross-sectional diagrams in the margin. By referring to those sketches as you read about river sedimentation, you will gradually come to understand how sediment accumulated in the Cumberland Basin during Carboniferous times.



The main features of sediment accumulation in a meandering river system

When rivers overflow their channels, the speed of the water slackens as it spreads out across the flood plain, reducing the water's capability of carrying particles as large as it could when moving swiftly in its confined channel. The larger particles are dropped as the water spreads out from the channel and accumulate to form embankments, or levees (A). After repeated floods, the river may flow at a higher level than the adjacent flood plain because it is confined between these dyke-like levees (B). At this stage severe flooding can happen during storms, when the fast-moving river may erode through its own levees and burst through onto the low-lying flood plain, spreading its load of coarse sediment across the flood plain as a "sheet sand"(C). At such times several metres of sand could accumulate on parts of the flood plain near the main channels. When this happened any abandoned former channels or "oxbow cut-offs" could fill up very quickly. These infilled river channels are preserved as swellings on the underside of the resistant sandstone beds in the cliffs at Joggins. When this cycle was complete, the river cut a new course across the flood plain and a new cycle began (D).



Silt and mud were deposited as sediments in different ways. The severe flooding described above burst through the levees, spreading sand over large parts of the flood plain near the channel. Farther away, the current would have decreased enough to allow silt and then mud to fall out of the water.

Occasionally, less violent floods overflowed the banks of the streams, spreading silt and mud over large areas. This slow deposition of layers of silt and mud, which were transformed later into siltstone and shale, came during periods of relative stability in the history of the area.

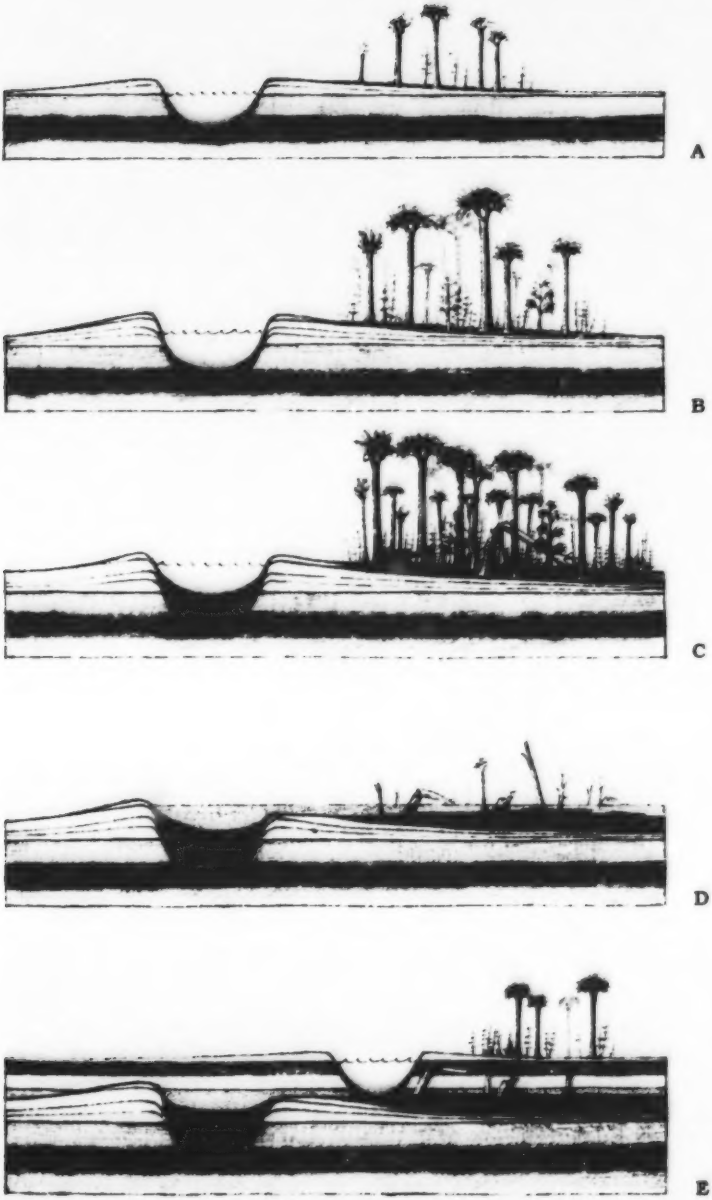
The sequence of diagrams on the next page shows how this situation affected vegetation and coal formation. Trees and other vegetation were able to grow on the flood plains during such times (A). You can see such layers of siltstone and shale at various levels all along the cliffs, and it is in those layers that we find the bottoms of the stumps and the roots of all the fossil trees at Joggins.

If the period of stability lasted long enough and no major floods killed off the vegetation, plant debris accumulated on the forest floor as a layer of peat (B). The longer the period of stability, the thicker the layer of peat (C). At some point, however, severe flooding once again burst through the levees, deposited a layer of sheet sand over the peat and killed the forest (D). Repeated floods would bring in more and more sediment. In due course, a forest was re-established and the cycle was repeated (E). Ultimately, under great compression from successive layers of sediment the layer of peat became coal. Look for layers of coal in the cliffs and on the beach.

A stable period lasting about 100 years would have been long enough for a jungle-like forest of large trees to grow, but not long enough for much peat to develop. Rock layers that preserve specimens of isolated tree trunks therefore represent periods of relatively rapid sedimentation, which brought short periods of stability to an end and killed off the forests before they developed peat floors.

During periods of relative stability abandoned channels could be filled up by a series of deposits from numerous small floods, rather than by a thick deposit of sand dumped during a major flood.

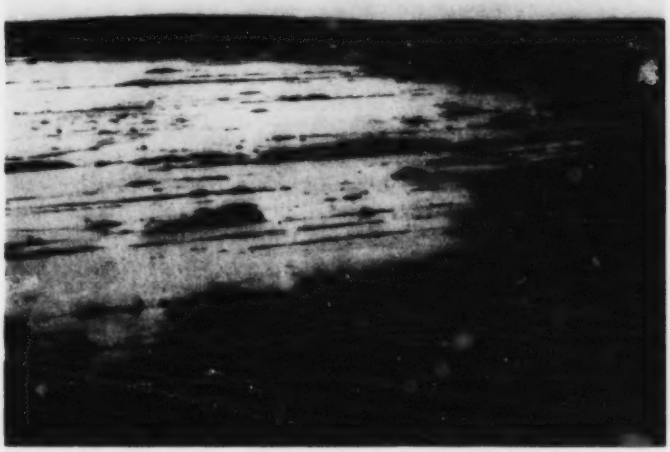
The diagrams on page 37 help to explain how the


A
B
C
D
E

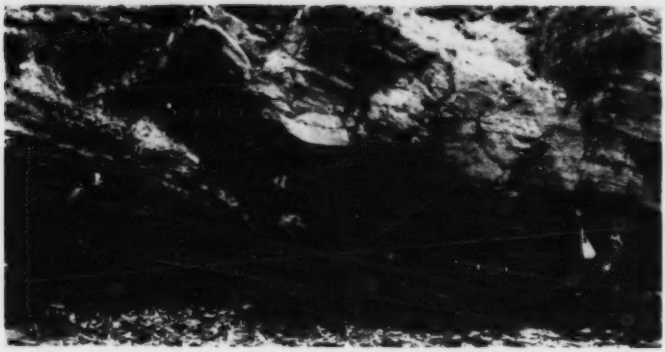
infilled channels shown in the accompanying photographs have come to be in the cliffs and on the beach at Joggins today. One set of inclined Carboniferous beds has been removed to show how an abandoned and infilled river channel is positioned on the surface of the bed (A). When the "slice" containing the infilled river channel is slid back into position, outcrops of channel deposits are visible on the upper (horizontal) surface and the vertical face (B). It is the coastal erosion of the cliffs (C) that has uncovered the outcrops of channel deposits we now see on the beach and in the cliff face.

Each layer of sediment, the edge of which we now see in the cliffs at Joggins, was once a flood plain crisscrossed by rivers and their tributaries. Think of the successive layers of flood plain deposits and channels as a great pile of leaves. The veins of these leaves are the rivers and the body of the leaf is the flood plain itself. The slightly different orientation of each successive "leaf" and its "veins" shows the changing patterns of the rivers over time.

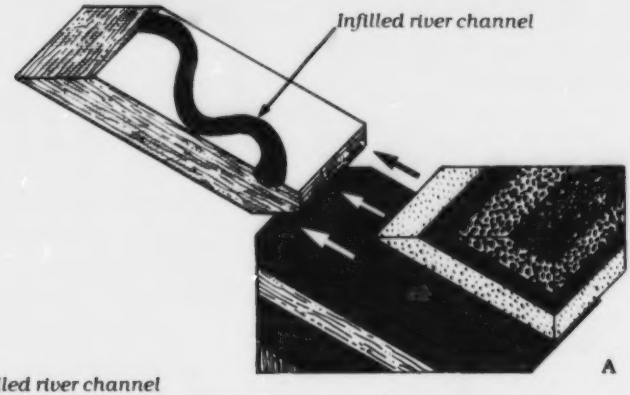
The infilled channels on the beach are easily seen from the tops of the cliffs when the tide is out. Close examination shows that they are most often masses of sandstone which project out from the undersides of sandstone beds—infilled river channels which have been more wave-resistant than the material that once surrounded them.

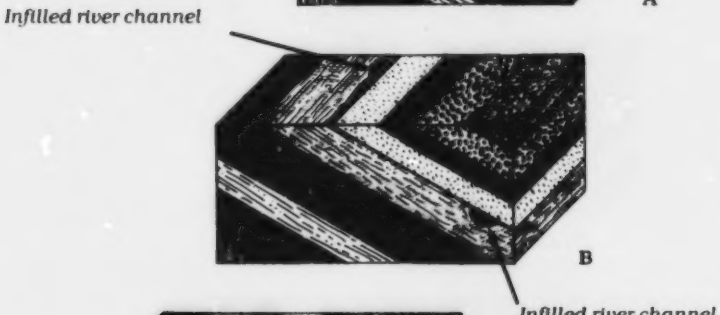


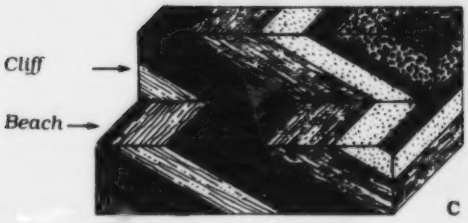
Infilled channels on the beach, seen from the cliffs



Infilled channel in the cliffs







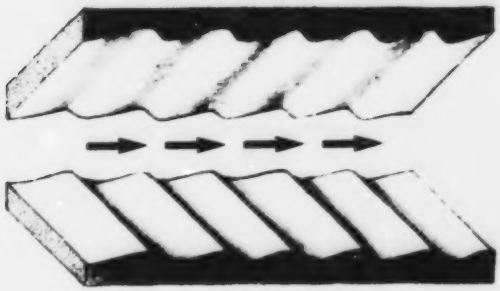
SEDIMENTARY STRUCTURES

Structures preserved in the sediment when it was deposited paint an interesting picture of the environment at that time. For example, certain types of ripple marks and other structures preserved in the sedimentary rocks can tell us the direction of the current that produced the ripple and transported the sediment. Other sedimentary structures can help us determine whether the sediment was deposited in a river, a lake or the sea, and whether it was laid down in an arid or a wet climate. Most sedimentary structures are also useful for determining whether the beds of rocks are in their normal position (with the oldest strata at the bottom of the pile) or have been turned upside down. The orientation of the fossil trees at Joggins tells us that the beds there have not been overturned because their roots are always lowermost.

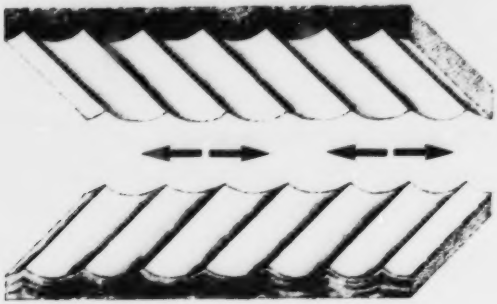
Here are some of the sedimentary structures you are likely to see at Joggins:

A:Structures that help geologists figure out the direction of the currents that transported the sediments at Joggins.

1. RIPPLE MARKS formed in soft sediment are often preserved once the sediment is converted to rock. Commonly the rock splits along the ripple-marked surfaces to reveal ripples made many millions of years ago. From these structures we can determine the direction and velocity of the current that formed them and, in some cases, even the depth of water in which they were formed. Basically there are two types of ripples: (1) CURRENT RIPPLES are asymmetrical in cross section and indicate the direction of the current that formed them; (2) WAVE RIPPLES are symmetrical in cross section and usually are formed by the to-and-fro movement of wave action on the sur-



Current ripples



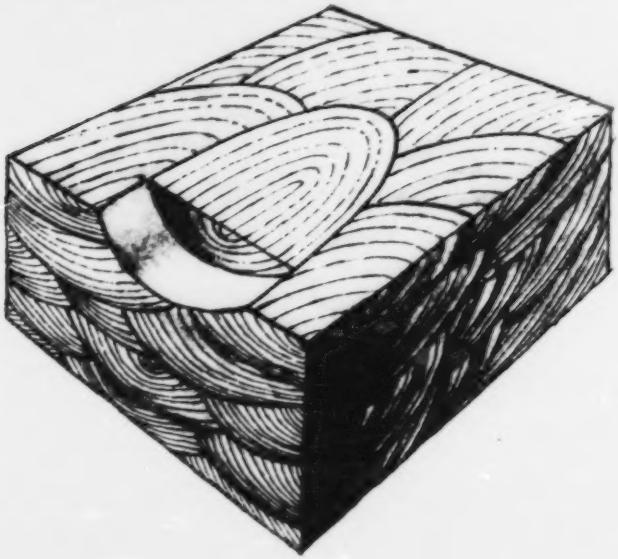
Wave ripples

face. These are normally only formed in relatively shallow water; current ripples may be formed in water of any depth.

2. TOOL MARKS are grooves made in soft sediment by some "tool," such as a partly floating tree branch being dragged along by the water current. These help determine the direction of the current.

3. CROSS BEDDING or CURRENT BEDDING is produced where sediment is moved and deposited by currents, which frequently changed direction. Such a bed is like a layer made up of many small adjacent deltas.

Through various sophisticated measurements of these cross-bedded units, geologists can figure out the direction of the flow of the river producing a delta and also the position of the source of the stream and its load of sediment.

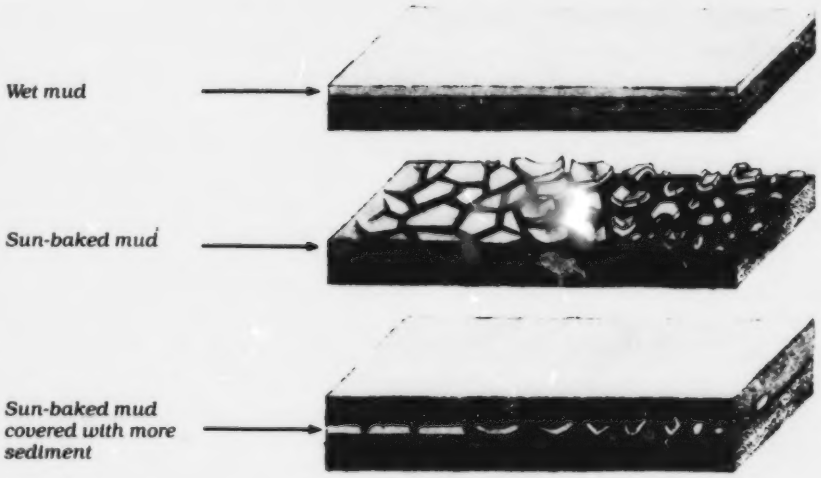


Cross bedding

Interpreted together, these sedimentary structures at Joggins indicate that the river system that spread these beds of sediment across the Cumberland Basin toward the north and east during the middle of the Late Carboniferous was bounded by the Caledonian Arch of southeastern New Brunswick to the west and by the Cobequid Arch to the south.

B: Sedimentary structures that help us understand what the environment was like when the various layers of sediment were deposited.

1. MUD CRACKS—When wet clay or mud dries in the sun, it contracts and cracks into polygonal plates. If they are buried by more sediment, at the next flood of the river, for example, the overlying sediment fills the cracks, covers over the polygons and preserves them. When mud cracks are found preserved in sedimentary rocks, it normally means that the sediment surface had been exposed to the air and that the sediment had been deposited on the land (that is, on a river flood plain) rather than in the sea or a deep lake.



2. CLAY GALLS—In some of the rock layers at Joggins you will come across clay galls, lens-like chunks of muddy sediment, usually bluish grey or reddish brown, caught up in the normally sandy rock.

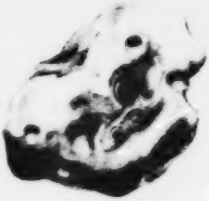
These are dried mud polygons that have been rolled around by subsequent floodwaters and smoothed into rounded clay aggregates that look like large chocolate buttons or chocolate drops, several centimetres across and usually about a centimetre thick. Clay galls suggest there has been exposure to the air between floods. Mud (or desiccation) cracks and clay galls were then buried by sediment during a subsequent flood.

3. RAIN PITS — When rain falls on soft mud it makes small circular craters. If the mud then dries out in the sun and becomes brick-hard, these craters can be preserved by the next influx of sediment, which buries them. Such rain pits preserved in a sedimentary rock also indicate a land environment and exposure to the air.

At Coal Mine Point several large slabs show ripple-marked surfaces spotted with rain pits. These slabs point to an interesting sequence of events. First, the shallow, wave-agitated waters that formed the ripple marks on the surface of the flood plain receded. Then, before the ripple marks had a chance to dry completely, they were pockmarked by rain. Next, the rain-pitted ripples dried in the sun. Finally, they were buried for posterity by the next flood of sediment.

4. TRACKWAYS — The footprints of amphibians, reptiles and very large centipede-like creatures that lived in the Joggins area in Pennsylvanian times have also been preserved in much the same way as the rain-pitted ripple marks. These tracks and trails confirm that these sediments were deposited by rivers and not within oceans.

5. IRONSTONE NODULES — You can often find yellowish brown stones that look like irregular potatoes on the beach at Joggins, and occasionally they are found concentrated in certain beds. These are nodules or concretions of siderite, an iron carbonate formed by precipitation from standing bodies of flood water that evaporated in the warm air. In some cases, the siderite formed in concentric layers around the remains of plants or other organisms. In others, the material was precipitated as thin extensive layers or beds, or the nodules were concentrated at certain levels within a tree stump. As mentioned above, sometimes the siderite even infilled the roots of trees.

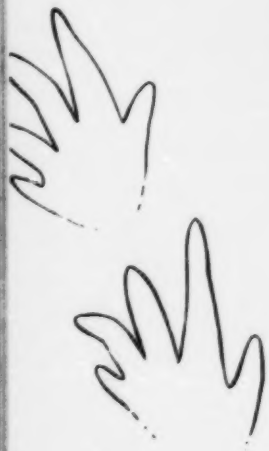


So by learning to "read" the sedimentary rocks at Joggins and the structures they contain, we get a picture of levee-bound river channels crossing low-lying marshy areas, which were flooded only occasionally and for long periods received only minor amounts of fine sediment. This slow accumulation of fine sediment permitted sizeable trees to thrive. During such periods of stability forests could establish themselves and, if the period was long enough, a layer of peat could develop. Eventually,

however, a major flood buried the area in coarse sediment, which was deposited around the bases of the trees and over the layers of peat. Much later, under the tremendous weight of accumulated layers of sediment, the peat became coal. The thinness of the seams of coal at Joggins suggests that the periods of relative stability were reasonably short.

Remember that we are thinking about incredibly long periods of time. No single environment would have persisted during the 10 million years that the thick succession of beds exposed at Joggins was deposited, and great variation is to be expected in such an extensive record. In other words, it is not surprising that different geologists have arrived at different pictures of the environment for different parts of the Section. Even so, there is general agreement that most of the layers of sediment at Joggins were deposited in some sort of river system that flowed across a rapidly sinking basin.

But why was the Cumberland Basin sinking? We can't fully understand Joggins until we realize that. It was *because* the Cumberland Basin was sinking 310 million years ago that it became a giant reservoir for sediment eroded from nearby mountains and carried into the basin by rivers. It was the collection of these sediments in the Cumberland Basin that made possible the fossilization of the plants and animals we find at Joggins today.



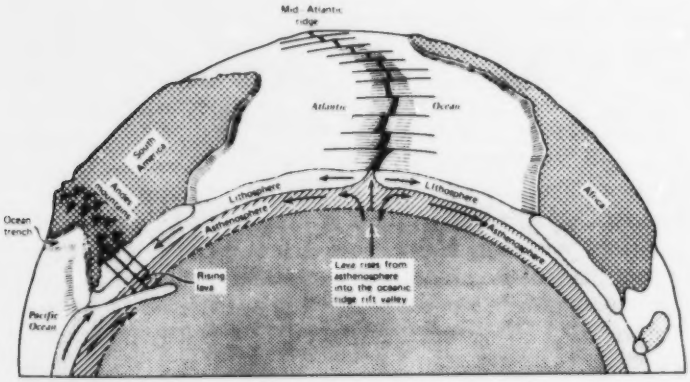
5

Where Joggins Fits in the Global Scene

CONTINENTAL DRIFT, OCEAN FLOOR SPREADING AND PLATE TECTONICS

To understand why the crust of the earth was sinking under the Cumberland Basin during the Late Carboniferous period and why Caledonia Mountain and the Cobequid Mountains remained as uplands, it helps to be familiar with current ideas about continental drift, ocean floor spreading and plate tectonics.

The crust of the earth is not as stable as we might think. Large segments or "plates" of it move with respect to one another in response to changing forces within the earth. When a hot, rising convection current of molten rock reaches the surface of the earth it spreads laterally, cools and sinks again. Where the current rises, lava spews out of a string of volcanoes along the cracks that develop when the crust is pulled apart, as shown in the diagram below. As the lava cools, new crust is formed and the ocean floor "spreads".



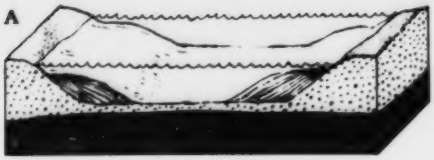
The overall effect is that the plates move away from such a spreading centre and continents on these moving plates "drift" away from the spreading centre and each other. Geologists have observed this phenomenon taking place in our present-day Atlantic Ocean at the Mid-Atlantic Ridge, and this has given rise to the theory of plate tectonics.

Once the convection current has cooled, it tends to sink back down into the earth and pull the lighter rocks of the crust down with it, forming a depression or trench in the crust known as a subduction zone. The crust of the earth is thus actually slowly mobile. Plates can move apart or toward each other. Plates can also slide sideways past each other, as they are doing near the coast of California at present along the San Andreas Fault. The spreading of the present-day Atlantic Ocean is perhaps the most obvious and best-documented example of what used to be called continental drift, a phenomenon that apparently has been going on for hundreds of millions of years.

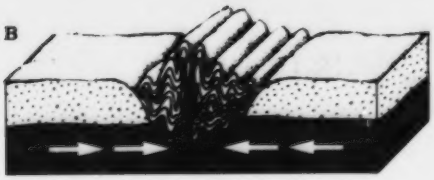
THE CLOSING OF THE "PROTO-ATLANTIC" OCEAN

About 600 million years ago there was a large ocean roughly on the site of the present Atlantic Ocean. This is often referred to as the Proto-Atlantic (A). In response to the movement of plates of the earth's crust, the Proto-Atlantic Ocean closed up about 450 million years ago (B). The layers of sediment on the edges of the colliding continents or opposing continental shelves crumpled up, or folded, into a long range of high mountains, including those now called the Appalachians, which extended up the eastern seaboard of North America, through the Maritimes and out to Newfoundland. Today they appear to terminate abruptly there, but the range actually continues through Northern Ireland, Scotland and Scandinavia. During Carboniferous times it was one continuous mountain range, rather than two separated by an ocean.

After the closing of the Proto-Atlantic and before the opening up of the present Atlantic Ocean, the area in which Joggins is situated experienced a period of "relaxation"(C). Later, great forces that had both brought the continents together and heaved up the mountain range

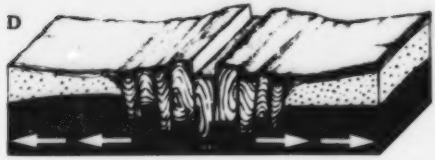


The Proto-Atlantic Ocean

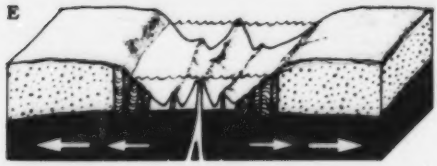


The formation of the Appalachians by colliding continents

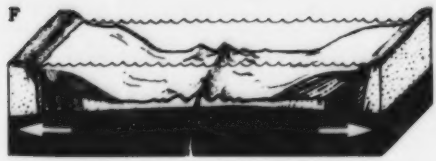
A period of "relaxation" and block-faulting



The earth's crust begins to pull apart again



Our present Atlantic Ocean is formed. The continents are being pulled apart over the spreading centre of the Mid-Atlantic Ridge



Sediment eroded from the continents is building out to form continental shelves at each side of the ocean

would eventually give way to other forces, which would pull the crust apart over a spreading centre (D); this spreading centre is now the Mid-Atlantic Ridge. Ultimately these later forces created the Atlantic Ocean (E). This process is continuing today, and as the ocean widens, new crust is being added at the mid-ocean ridge. At the same time, sediment eroded from the adjacent continents is building out to form the continental shelf at each side of the ocean (F).

BLOCK-FAULTING

However, after the Appalachians were formed, during the period of relaxation from the horizontal forces, the area in which Joggins is now situated became subject to vertical forces as the crust attempted to regain its equilibrium or balance. This readjustment caused the crust to break up along large cracks or faults into a series of "blocks" or segments. Some of these blocks rose up relative to their neighbours and some went down. For example, Caledonia Mountain and the Cobequid Mountains rose up and the Cumberland Basin sank. So this period of block-faulting after the actual formation of the Appalachian mountain range is especially significant in connection with the sediments and fossils preserved at Joggins.

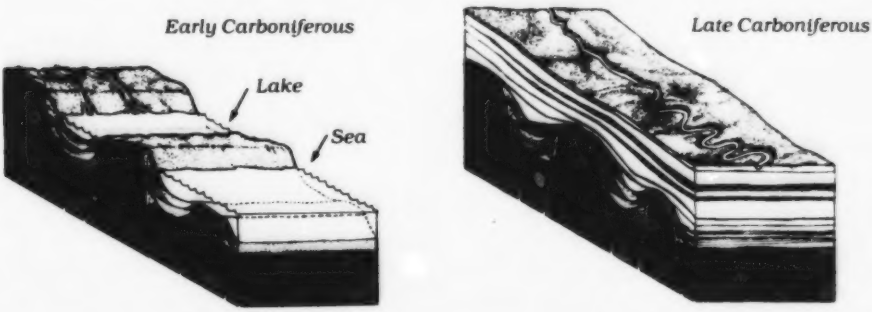
The period of readjustment of the earth's crust in the area where the Appalachian Mountains had been raised occurred between 350 and 320 million years ago, during the Late Devonian and Early Carboniferous periods of geological time. During the initial readjustment more or less vertical faults occurred. Some blocks (several tens of kilometres across) slid upward, while others either stayed put or were forced down between uprising blocks. The uplifted blocks were rapidly eroded, and the debris was swept into the intervening rift valleys either by streams or by gravity.

Rivers and streams drained into the basins and, if there was no direct connection between them and the open sea or ocean, a lake was formed. One such lake occupied what is now Albert County in New Brunswick. "Lake Albert" teemed with fish and algae and their remains were locked up in the lake sediments to provide the source of

the hydrocarbons still being extracted from eastern Canada's only producing oil and gas field, near Moncton.

Where there was access to the sea, and the basin lay below sea level, the sea would fill up the basin and it would become a branch of the sea, often with relatively poor circulation to the open sea. In such circumstances the sea water evaporated and various salts were precipitated to form layers in the bottom of the basin. Economically important "evaporites" formed in this way include such deposits as the Windsor Limestone series of both Nova Scotia and New Brunswick; the gypsum deposits of Rawdon, Nova Scotia, and Hillsborough, New Brunswick; the rock salt deposits at Pugwash and Amherst, Nova Scotia; and the potash deposits of the Sussex area in New Brunswick.

The numerous smaller basins that formed in the central Maritimes in Late Devonian and Early Carboniferous times were gradually filled in by sediment derived from the erosion of the neighbouring mountainous areas. By Late Carboniferous times, when the beds of sediment at Joggins were laid down, only the larger uplifted and resistant blocks, such as the Caledonia Mountain area and the Cobequid Mountains, remained as highlands. The Cumberland Basin, which lay in between, had been more or less "levelled out" and had become a vast river plain which, as far as we can figure out, sloped northward from the highlands to the area now occupied by Prince Edward Island and beyond. The block diagram on the right shows what this looked like. You can see that sediments and coal layers deposited during Late Carboniferous times have completely buried the underlying small evaporite basins and lake sediments of early Carboniferous times.



The rivers that criss-crossed the area carried sediment toward a sea that lay somewhere to the north. When the Cumberland Basin was sinking slowly, lush vegetation grew on the flood plains between the rivers, and trees about 30 metres high formed the main components of a jungle-like forest.

Some of the first reptiles on earth walked beneath those trees.

Coal Age forest

6

Joggins in a Nutshell

In response to the movement of convection currents within the earth, the Proto-Atlantic Ocean closed about 450 million years ago and raised up a huge mountain range that included the Appalachian Mountains and their continuation in northwestern Europe. Before this range was torn apart and the present Atlantic Ocean began to form (about 200 million years ago), the mountain range went through a period during which equilibrium was re-established. Block-faulting occurred. Some blocks were raised up considerably, while others sank relative to them and became the sites of accumulation of debris eroded from the higher blocks.

The Cumberland Basin was one of the low areas, and it received sediment from rivers coming from the uplifted highlands to the south and west. The great pile of sediments exposed at Joggins records the river sedimentation that happened during this block-faulting phase about 300 million years ago.

The vegetation that grew on the river flood plains is preserved in several ways—sometimes as coal beds, resulting from peat accumulation when the sinking of the crust and sediment accumulation were slow, and sometimes as individual drowned forests formed when sinking and sedimentation occurred more rapidly. About 65 coal-forming periods and 40 drowned forests have been identified in the Joggins Section.

The fossil tree stumps preserved in the drowned forests contain the remains of amphibians and of some of the very first reptiles that evolved on earth. These creatures fell into the hollow tree stumps just before the stumps were filled in completely by sediment spilling in over their rims.

Joggins provides scientists with a rare opportunity to find specimens of the first land reptiles to evolve on earth—ancestors of the dinosaurs that later were to dominate the planet for about 160 million years, until

they themselves became extinct about 60 million years ago.

Visit Joggins yourself and discover some of the same clues geologists used to unravel this small piece of the earth's story.

Bibliography

Bell, W.A., 1914. *Joggins Carboniferous Section, Nova Scotia.* Geological Survey of Canada, Summary Report for 1912, pp. 360-371.

Bell, W.A., 1944. *Carboniferous Rocks and Fossil Flora of Northern Nova Scotia.* Geological Survey of Canada, Memoir 238.

Calder, J.H., 1985. *Coal in Nova Scotia.* Nova Scotia Department of Mines and Energy, pp. 1-79.

Carroll, R.L., 1964. *The Earliest Reptiles.* Journal of the Linnean Society (Zoological), v. 45: 61-83.

Dawson, J.W., 1882. *On the Results of Recent Explorations of Erect Trees Containing Animal Remains in the Coal-formation of Nova Scotia.* Royal Society of London, Philosophical Transactions, v. 173 (part 2):1-659 (plus plates).

Dawson, J.W., 1891. *The Geology of Nova Scotia, New Brunswick and Prince Edward Island* or *Acadian Geology,* 4th ed. (with 2 supplements), MacMillan & Co., London.

Duff, P.McL.D., and Walton, E.K., 1973. *Carboniferous Sediments at Joggins, Nova Scotia.* Seventh International Congress of Carboniferous Stratigraphy and Geology, v. 2: 365-379.

Ferguson, L., 1975. "The Joggins Section," in *Ancient Sediments of Nova Scotia,* I.McK. Harris, Ed. Guidebook for 1975 field trip, Eastern Section, Society of Economic Paleontologists and Mineralogists, pp. 11-118.

Gersib, G.A., and McCabe, P.J., 1981. "Continental Coal-bearing Sediments of the Port Hood Formation (Carboniferous), Cape Linzee, Nova Scotia, Canada," in *Recent and Ancient Nonmarine Depositional Environments: Models for Exploration,* F.G. Ethridge and R.M. Flores, Eds. Special Publication, Society of Economic Paleontologists & Mineralogists, Tulsa, v. 31: 95-108.

Gibling, M.R., 1987. *A Classic Carboniferous Section: Joggins, Nova Scotia.* Geological Society of America Centennial Field Guide, Northeastern Section, 5 (88): 409-414.

Rust, B.R., Gibling, M.R., and Legun, A.S., 1984. *Coal Deposition in an Anastomosing-Fluvial System:The Pennsylvanian Cumberland*

Group South of Joggins, Nova Scotia, Canada. International Association of Sedimentologists Special Publication 7, pp. 105-120.

Stanley, S.M., 1985. *Earth and Life Through Time.* W.H. Freeman and Company, New York.

Stea, R.R., Finck, P.W. and Wightman, D.M., 1986. *Quaternary Geology and Till Geochemistry of the Western Part of Cumberland County, Nova Scotia (Sheet 9).* Geological Survey of Canada, Paper 85-17.

Stewart, W.N., 1983. *Paleobotany and the Evolution of Plants.* Cambridge University Press.

Zodrow, E.L., and McCandlish, K., 1980. *Upper Carboniferous Fossil Flora of Nova Scotia.* The Nova Scotia Museum, Halifax.

What was going on at Joggins 300 million years ago and why are geologists from around the world so interested? The cliffs at Joggins contain the clues. **THE FOSSIL CLIFFS OF JOGGINS** will help you understand them.

DR. LAING FERGUSON has been Head of the Department of Geology at Mount Allison University in Sackville, New Brunswick, for the last fifteen years and has visited Joggins regularly for at least twenty-five years.

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